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GAMMA-RAY SPECTRUM FROM THE RADIATIVE CAPTURE OF 14 MeV NEUTRONS IN Al^{27}

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Radiative capture reactions with medium energy neutrons have been investigated experimentally in a very limited extend. In this energy region only activation measurements of the total cross section for 14 MeV neutron capture on a number of elements have been done [1]. In the region of low mass number the cross sections from the activation measurements are of the same order of magnitude as given by the statistical theory, in the case of heavy nuclei the calculated cross sections are three to five orders of magnitude smaller than the experimental values. Beck [2] and Lane and Lynn [3] proposed the direct reaction mechanism in order to explain the discrepancy. One could expect that the measurement of the energy spectra of the medium energy neutron capture gamma-rays would give further insight in the reaction mechanism.

In this paper a method for the measurements of gamma-ray energy spectrum from 14 MeV neutron capture is described and first results on Al^{27} are presented.

The gamma-ray spectrum from the reaction Al^{27} (n, γ) Al^{28} induced by 14 MeV neutrons was measured using an improved version of the telescope scintillation pair spectrometer described previously [4]. Following improvements were made: 1) the distances between scintillators were reduced, so that the natural background was lowered to about 1 cpm in the gamma-ray energy interval from 0 to 25 MeV, 2) the faster electronics (70ns resolution time) was used, 3) the entrance of the linear amplifier in the main scintillator circuit was biased by a fast diode clipper in order to cut off recoil proton pulses from the main scintillator . The block scheme of the spectrometer is shown in fig. 1.

The spectrometer efficiency was measured at the energy of 11,7 MeV using 11,7 and 4,4 MeV gamma lines from the reaction B^{11} (p, γ) C^{12} at the 163 keV resonance. The source was monitored by a 4" dia. 4" thick Na I (Tl) crystal of known efficiency for 4,4 MeV gamma-line. At higher energies the spectrometer efficiency was corrected for the energy variation of the pair creation cross section.

The target assembly is shown in fig. 2. The target was 6 cm dia. aluminum ball placed around the neutron source. This arrangement introduces an energy spread of neutrons from 13,5 to 14,7 MeV. In order to lower the number of recoil protons in the main scintillator a paraffin cone was inserted betwen the target and the spectrometer.

Measurements were carried out at the rate of 5×10^7 neutrons per second, the flux being limited by the number of pile-up processes and the fact that the gain of the photomultiplier in the main scintillator circuit was found to decrease at higher pulse rates.

The energy distribution of gamma-rays from the reaction Al^{27}(n, γ) Al^{28} is shown in fig. 3. The energy scale was corrected for the nonlinearity introduced by the use of a diode clipper as well as for the nonlinearity of the photomultiplier. The uncertainty of the energy scale at energies higher than 18 MeV is about 5 %. The ratio of the measured spectrum to the background was about 3 : 2. This large background was due to gamma-rays from the radiative capture of neutrons in the materials around the spectrometer and to

accidental coincidences of pile-up spectrum of recoil proton pulses from the main scintillator and recoil proton pulses from the scintillator CO.

The binding energy of neutron in Al^{28} is 7,8 MeV, so the gamma-ray spectrum in the energy region from 14 to 21,8 MeV represents transitions to bound states of Al^{28}. This part of the spectrum includes gamma-rays from the capture processes in which the emission of one photon leads directly to a bound state („one photon capture" according to Lane and Lynn's paper). The contribution of processes in which two (or more) photons are emitted before a bound state is formed („two photon capture") should be negligible in this energy region. For the cross section integrated over gamma-ray energies higher than 14 MeV we found the value of $0,26 \pm 0,05$ mb. The statistical error is about 7 %, the rest of the inaccuracy is mainly due to the uncertainity in the spectrometer efficiency and the neutron flux determination. (The uncertainity of the tabulated semiempirical intrinsic efficiency of the 4" dia. X 4" thick NaI crystal was taken to be 10 %.)

The value of the cross section obtained by activation measurements is $0,53 \pm 0,13$ mb. The activation measurements include also all cascade processes through unbound states of Al^{28}. We can not measure gamma-rays from cascades through the levels of Al^{28} in the excitation energy range from 7 to 14 MeV, because they can not be resolved from gamma-rays accompagniing inellastically scattered neutrons. Supposing that the cascade deexcitation through the unbound states of Al^{28} involves only the states in this energy interval, a value of $1 \pm 0,5$ for the ratio of two (or more) photon to one photon capture is obtained from the difference of our cross section and the cross section measured by the activation method.

The calculated cross section for the reaction $Al^{27}(n, \gamma)Al^{28}$ according to the statistical theory is 0,13 mb. (In this calculation Newton level density formula and the photon absorption cross section from the paper of Lane and Lynn have been used.) Taking into account the uncertainity of the absolute cross section calculation, one can say that the statistical theory gives the cross section of the right order of magnitude. On the other hand the shape of our spectrum does not agree with the spectrum shape predicted by the evaporation theory. It is interesting to note that two peaks in our spectrum correspond to two strong proton groups from the reaction $Al^{27}(dp)Al^{28}$ at the same excitation energies [5,6]. The observed angular distributions of protons from theese two groups indicate the direct interaction. Therefore one can expect that the corresponding direct process takes part also in the $Al^{27}(n \gamma) Al^{28}$ reaction mechanism [7,8,9].

More accurate measurements on Al and other elements are in progress.

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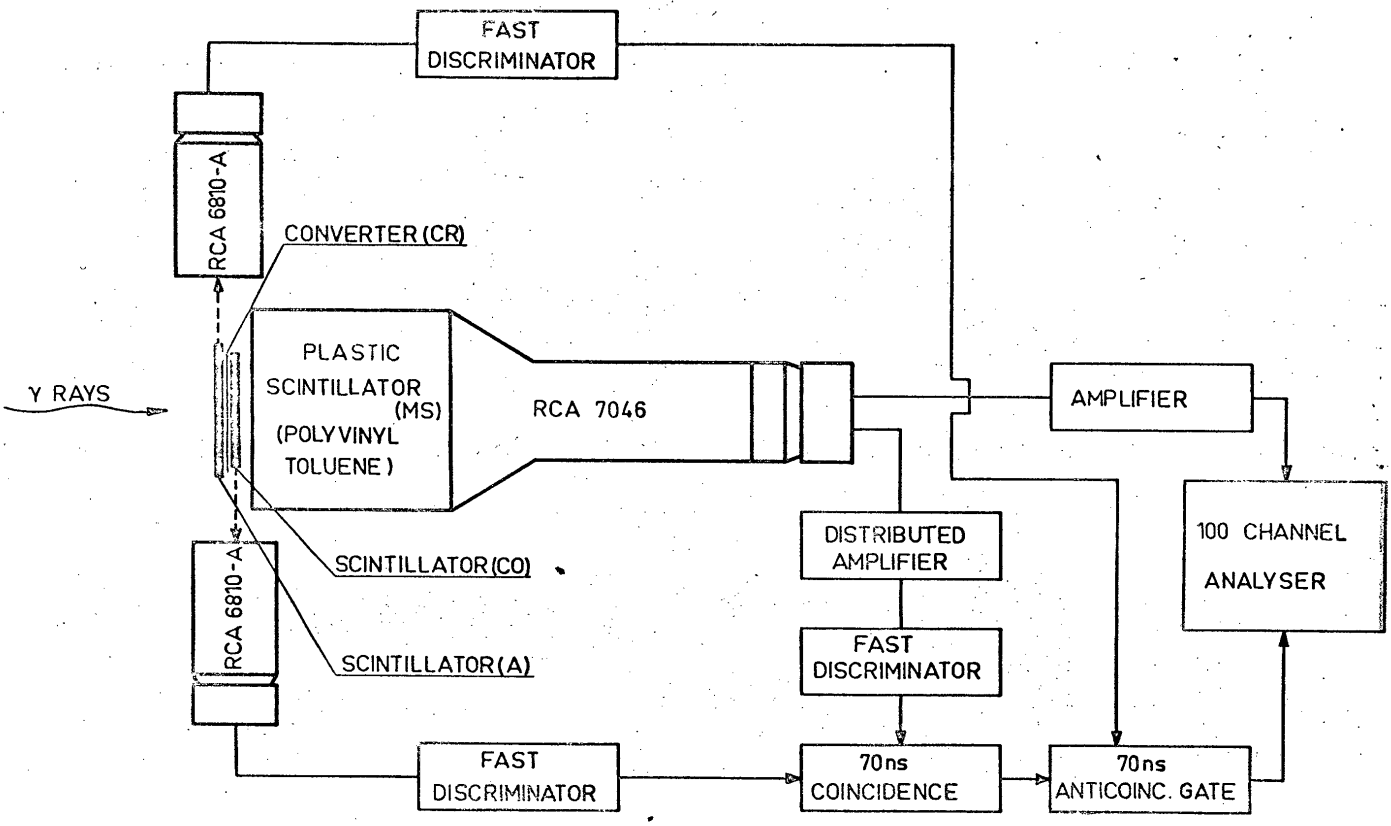


Fig. 1. Schematic diagram of the telescope scintillation pair spectrometer and the electronic equipment.

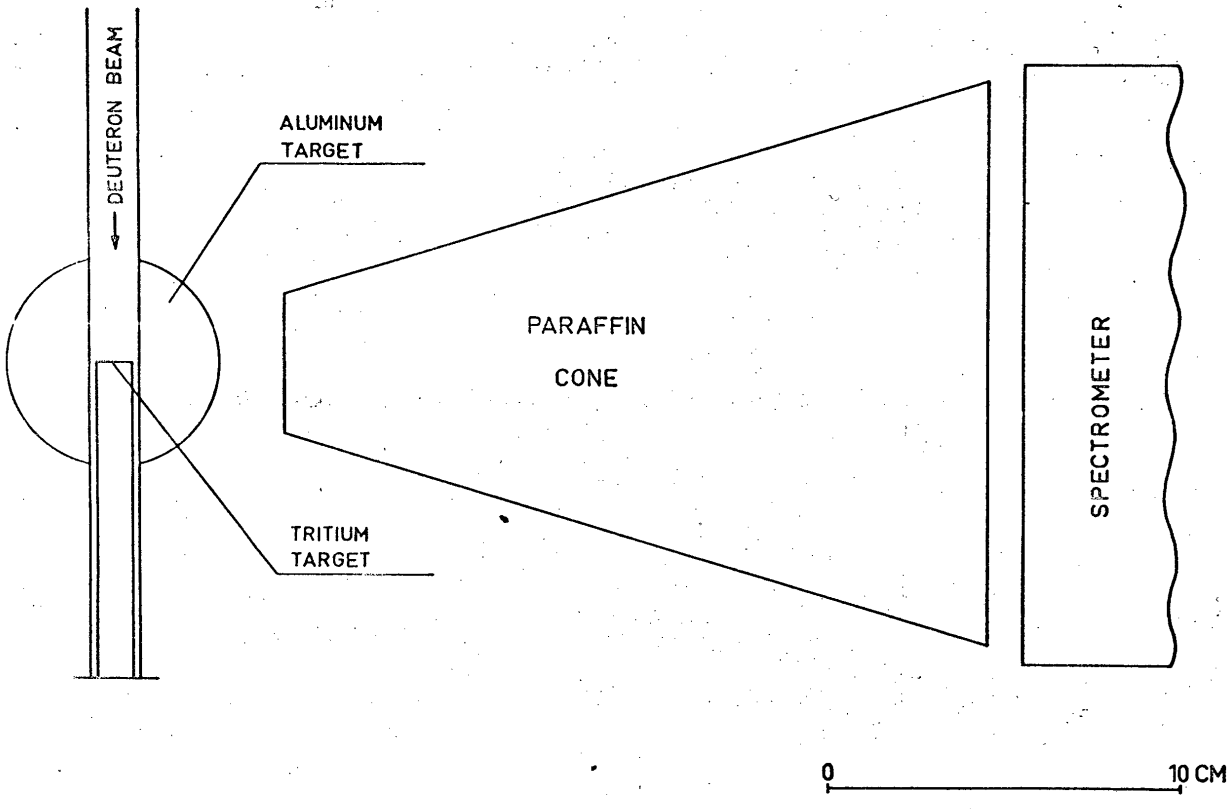


Fig. 2. Target assembly

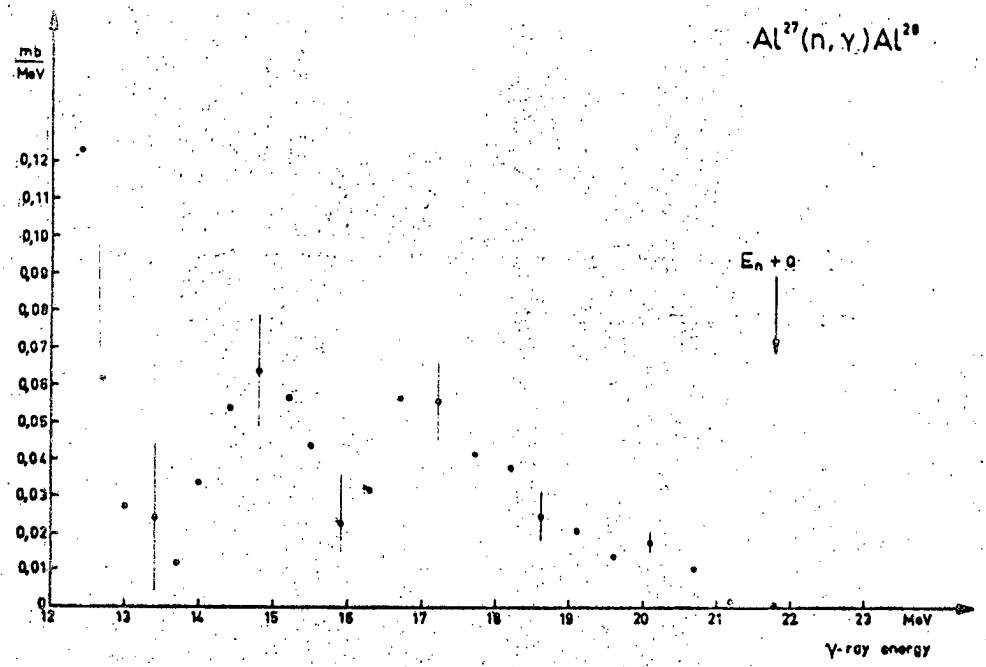
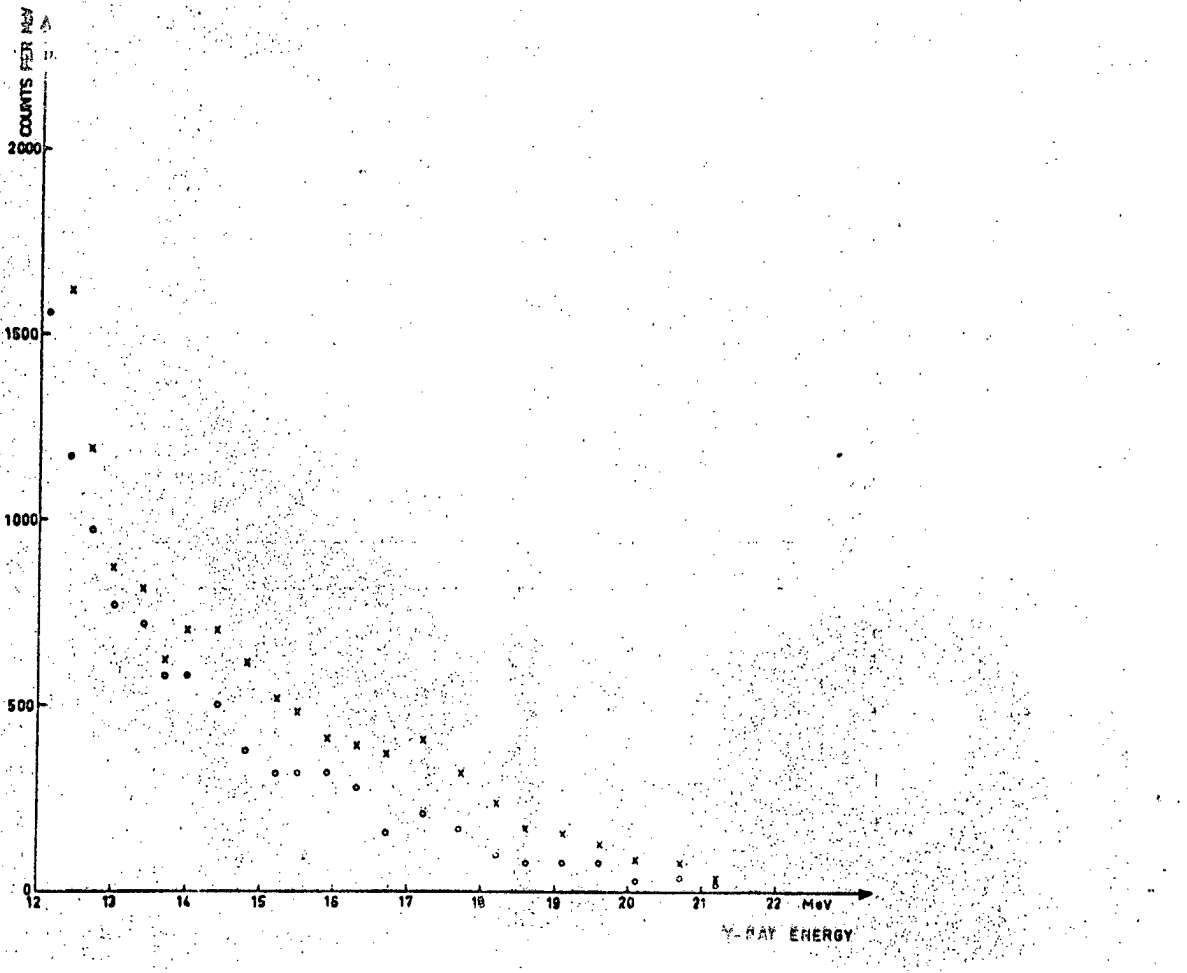


Fig. 3. Spectrum of γ-rays from the reaction $Al^{27}(n,\gamma)\ Al^{28}$.



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A TELESCOPE PAIR SPECTROMETER FOR 5–20 MeV GAMMA-RAYS

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In the following the principles and the performance of a telescope scintillation pair spectrometer constructed for measurements of γ-rays in the energy region from 5 to 20 MeV are reported.

The schematic diagram of the spectrometer is shown in fig. 1. Electron-positron pairs generated in the lead converter Cr pass the thin plastic scintillator Co and are stopped in the main polyvinyltoluene scintillator MS. Pairs coming from the target and the surroundings induce pulses also in the thin scintillator A. Pulses from scintillators Co and A are fed to an anticoincidence gate circuit triggering the linear gate of a multichannel analyser. In such a way the analyser registers only pairs created in the converter. Compton electrons produced by γ-rays give in the scintillator Co pulses which are approximately two times smaller than those of pairs. The proper adjustment of the level of the single channel analyser in the Co circuit reduces for about 3 times the number of measured Compton electrons coming from the converter and the scintillator Co.

The dimensions of the main scintillator and the scintillators A and Co are 12.5 cm dia × 12.5 cm, 8 cm dia × 3 mm, 7 cm dia × 2 mm respectively. The distance between the main scintillator and the scintillator Co is 19 mm, and that between the scintillators Co and A is 30 mm. The converter of the thickness 0.14 mm has the diameter of the scintillator Co and is attached on it.

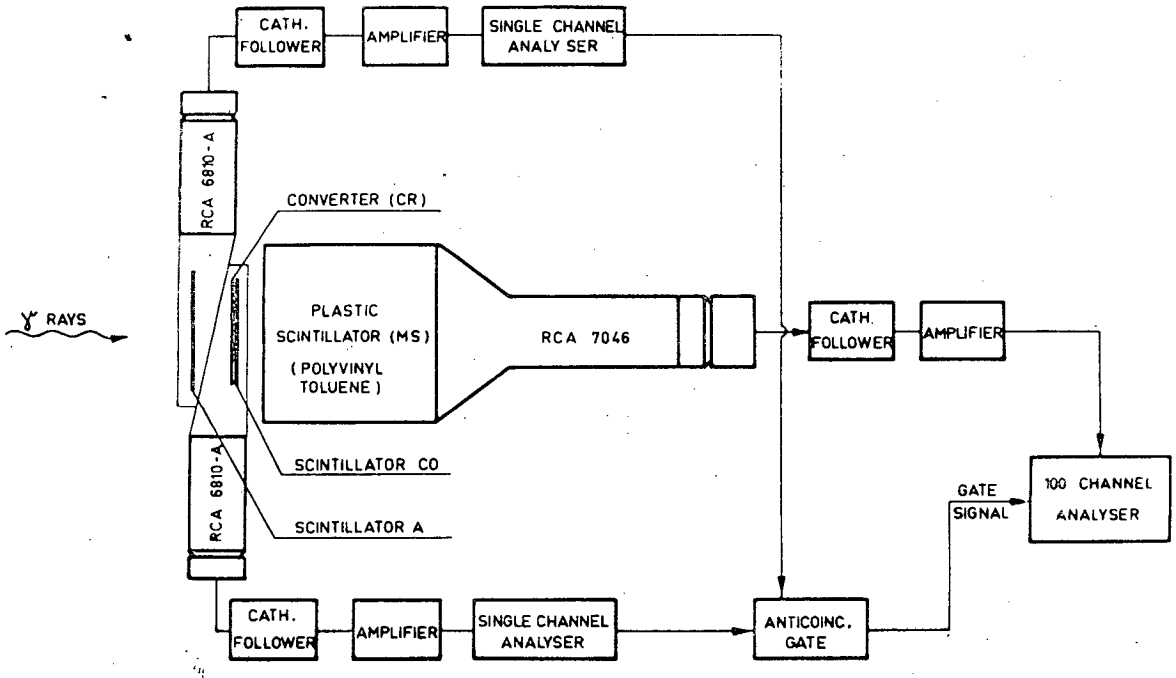

Fig. 1. Schematic diagram of the spectrometer.

The RCA 7046 photomultiplier following the main scintillator gives output pulses of about 20 nsec, so that the spectrometer could be made fast using nanosecond pulse technique. The spectrometer described in this note, however, uses slow (4 μsec) electronics.

The performance of the spectrometer was examined using gamma-rays of 11.7 MeV from the reaction $B^{11}(p, \gamma)C^{12}$ at the 163 keV resonance. The pulse height distribution is shown in fig. 2. Measurements of the same spectrum by the main scintillator itself have shown that the position of the peak in the figure corresponds to the energy of a double escape peak. The high intensity part of the spectrum at low energies is due to 4.4 MeV gamma-rays from the same reaction. The dashed curve represents the background spectrum which is believed to be caused by mesons coming into the spectrometer from the directions unprotected by the scintillator A. Preliminary measurements have shown that it is possible to remove most of the background reducing the distance between scintillators A and Co.

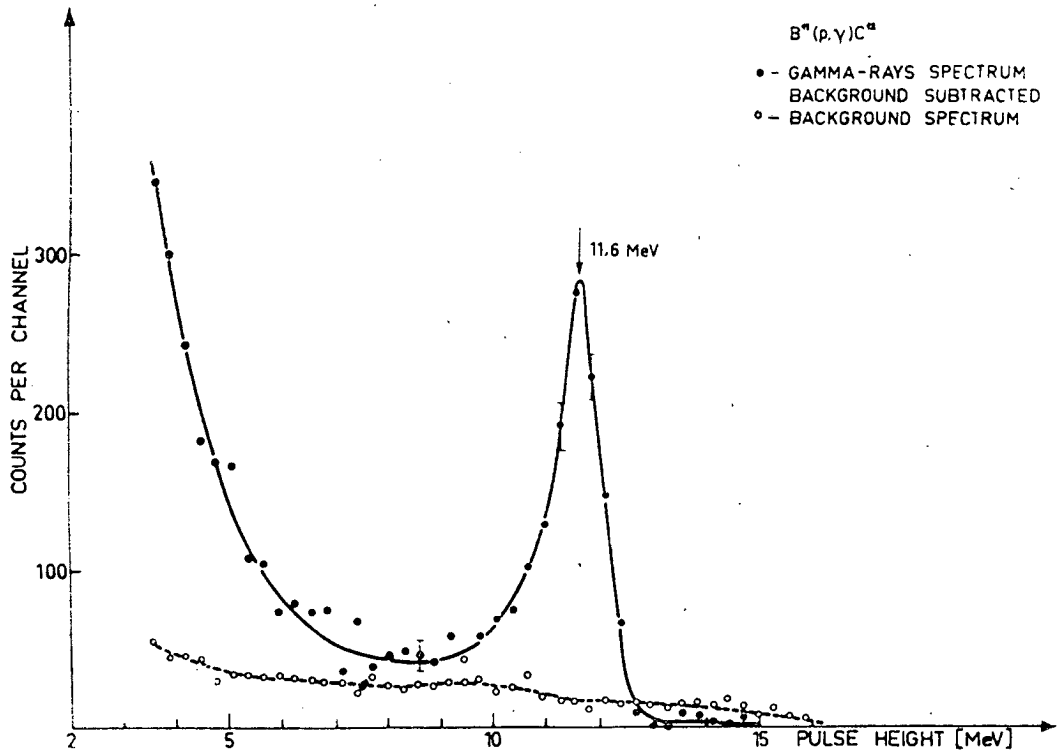

Fig. 2. Gamma-rays spectrum from the reaction $B^{11}(p, \gamma)C^{12}$.

The energy resolution of the spectrometer is found to be 9% for 11.7 MeV gamma-rays. The efficiency at this energy is approximately 0.6%, in accordance with the estimated value. Both values are determined primarily by the converter thickness, the energy resolution being chiefly affected by the ionization and radiation energy loss and the multiple scattering of pairs in the converter.

Authors wish to express their appreciation to Dr. U. Stierlin who suggested the construction of the spectrometer. We are indebted to Dr. D. Jamnik for many helpful discussions.

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